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Development of Hitachi Oxy-fuel Combustion Technologies

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Abstract

Babcock-Hitachi K.K. (BHK) has been developing a system for oxy-fuel combustion that achieves greater reliability with high efficiency. Features include:
(1) Gas Cooler; Mercury and SO_3 removal by decreasing flue gas temperatures at the ESP inlets. There is a large increase power in LP turbine output because the gas cooler preheats boiler feed water and reduces steam extraction from LP turbine.
(2) Stable combustion under low O_2 concentration of primary gas with NR-LE Burners
(3) Oxy-fuel combustion with O_2 concentration at 27~30 % takes the same heat absorption as Air combustion.

Keywords: Oxy-fuel, Boiler, Burner

1. Introduction

Increasing energy efficiency, utilizing low carbon fuels, and carbon sequestration are keys to reduction of greenhouse gas emissions. Carbon capture and sequestration from power plants are important as a substantial portion of greenhouse gas emissions are from power generation sources, especially coal-fired power plants. Babcock-Hitachi K.K. (BHK) has been developing two key technologies of CO_2 capture from coal-fired power plants: CO_2 scrubbing and oxy-fuel combustion [1]. Oxy-fuel combustion is an effective method in removing all CO_2 from combustion flue gas. Oxy-fuel combustion systems can be retrofitted to existing power plants with no change to plant water-steam cycles and only limited modifications to the boiler. Coal fired power plants are currently the leading source of power generation

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in the world, and BHK has contributed to current problem solving with a new system for oxy-fuel combustion that is reliable and highly efficient.

Features of this system include:

(1) Mercury and SO_3 removal by decreasing flue gas temperature at ESP inlets with a gas cooler system.

(2) A large increases power of LP turbine output (18MW for a 500MW class unit) as the gas cooler preheats boiler feed water and reduces steam extraction from LP turbine.

(3) Improvement of plant net efficiency (2.0 percents).

(4) Stable combustion under low O_2 concentration of primary gas with a new burner.

(5) Oxy-fuel combustion with O_2 concentration at 27~30 % takes the same heat absorption as air combustion.

This paper focuses on BHK's new oxy-fuel combustion system.

This study was partly carried out under contract with New Energy and Industrial Technology Department Organization (NEDO) of Japan, and partly co-researched with FORTUM OYJ.

2. An advanced oxy-fuel combustion system (Gas cooler system)

2.1. Experimental apparatus

The oxy-fuel combustion system has some corrosion potentials; one is mercury in flue gas which may cause corrosion in CO_2 purification and compression units [2], and one is SO_3 which may cause acid corrosion in recirculation gas ducts [3].

BHK has developed a unique flue gas treatment system with a gas cooler before the ESP, which has been applied to actual boilers as shown in Fig.1 [4]. The system with gas cooler has been applied to oxy-fuel combustion systems as well. By reducing recirculation gas temperatures below 90 °C, the Hg removal across the ESP could be improved, and SO_3 concentration is reduced to less than 1 ppm, by which corrosion is negligible.

BHK conducted tests using a 1.5MWth Combustion & AQCS (Air Quality Control System) test facility (Fig.2), which consists of oxygen supply unit, a furnace, an SCR, a heat exchanger, an ESP, a flue gas recirculation system and Wet-FGD [5]. This study was partly carried out under contract with New Energy and Industrial Technology Department Organization (NEDO) of Japan.

The analysis of coal tested in this study is shown in Table 1. Coal A is bituminous with high Hg content from China, and coal B is bituminous with high sulfur from the USA.

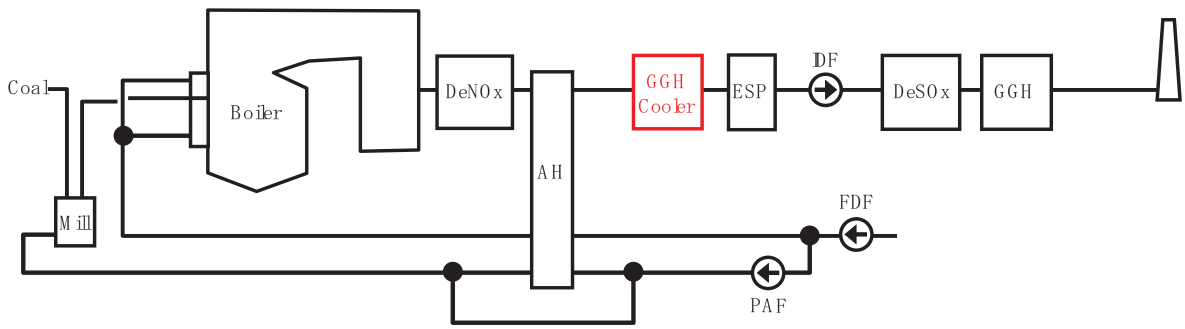


Fig.1 ESP Inlet Cooler System applied to Air Combustion [4]

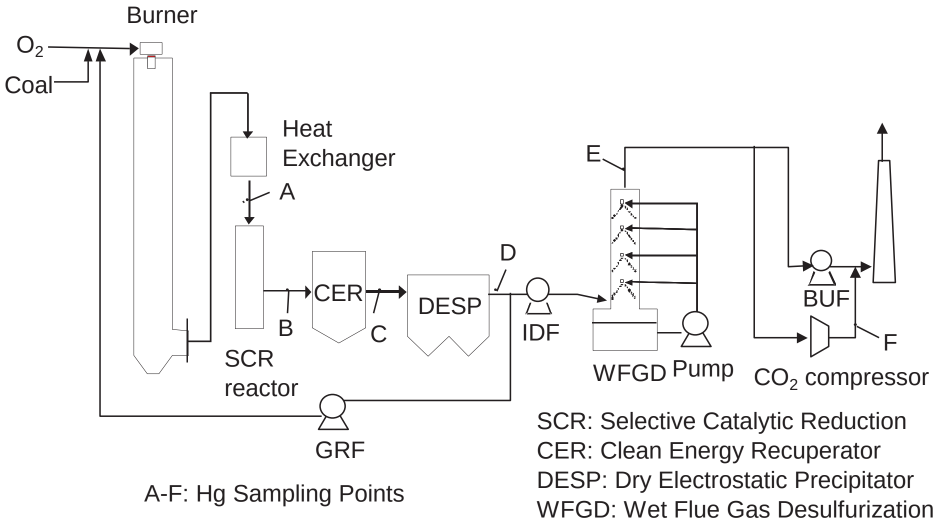


Fig.2 Schematic diagram of 1.5MWth Combustion and AQCS test facility [5]

Table 1. Analysis of the test coal

	base	unit	Coal A	Coal B
HHV	air dried	kJ/kg	15,660	27,330
Proximate Analysis:				
Moisture	air dried	%	2.0	9.2
Volatile Matter	dry	%	19.0	40.4
Fixed carbon	dry	%	33.0	50.2
Ash	dry	%	48.0	9.4
Ultimate Analysis:				
C	dry ash free	%	40.9	71.8
H	dry ash free	%	2.3	4.7
O	dry ash free	%	8.0	10.2
N	dry ash free	%	0.6	1.3
S	dry ash free	%	0.8	2.7
Hg	dry ash free	ppb	198	130
Cl	dry ash free	ppm	410	300

2.2. Results and Discussions

Fig.3 shows the Hg removal efficiency across ESP in coal A. In system without gas cooler, the Hg removal efficiency was around 20%, while the Hg removal efficiency was over 80% with a gas cooler system.

Fig.4 shows the SO_3 concentration at the ESP outlet. In systems without a gas cooler, SO_3 concentration was around 30ppm, while SO_3 concentration was below 1ppm with a gas cooler system.

SO_3 concentration profiles in AQCS are shown in Fig.5. The gas cooler reduces SO_3 concentration to below 1ppm at the ESP Inlet.

The mechanism for SO_3 removal with a cooler system [7] is shown in Fig.6. At flue gas temperature in below acid dew point, SO_3 gas contained in flue gas changes to mists (liquid) and sticks to coal ash particles, which are caught by the ESP. SO_3 mists are neutralized by alkalis contained in ash, so that corrosion of the ESP material is prevented.

We carried out corrosion tests in a comprehensive system test facility consisting of a combustion system with environmental equipment. As the result show in Fig.7, in systems without a gas cooler, acid corrosion appeared in the re-circulation gas duct. However in systems with a gas cooler, acid corrosion did not appear at the recirculation gas duct.

The gas cooler system reduces SO_3 concentration below 1 ppm at the ESP Inlet. The value of 1 ppm is enough to avoid acid corrosion of carbon steel material of the flue gas and recirculation gas ducts.

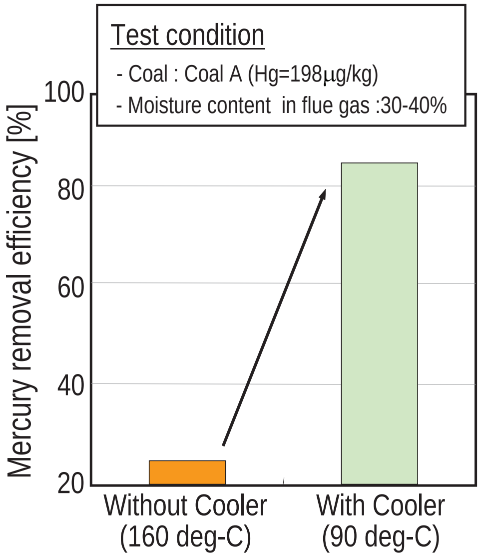


Fig.3 Hg removal efficiency across ESP [5]

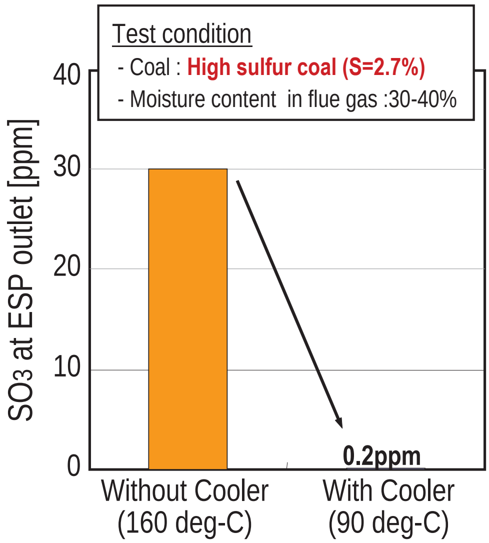


Fig.4 SO_3 concentration at ESP outlet [6]

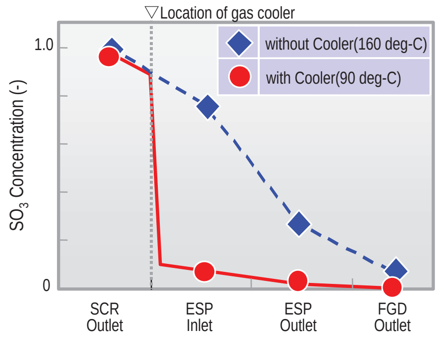


Fig.5 SO_3 concentration profiles in AQCS [7]

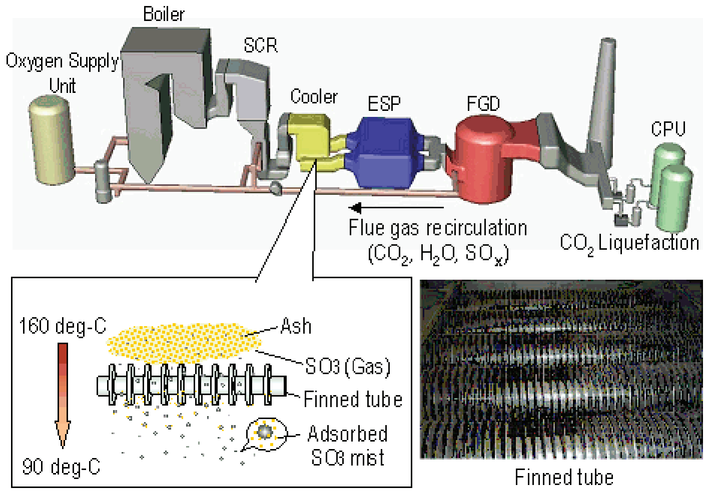


Fig.6 Mechanism of SO_3 removal with cooler system [7]

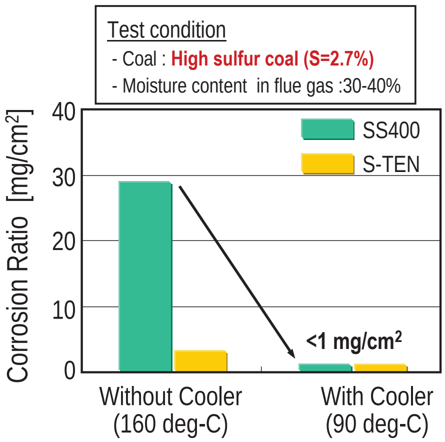


Fig.7 Acid corrosion rate at re-circulation gas duct [8]

2.3. Feasibility studies for 500 MW class power plants

A key design issue for oxy-fuel combustion is the arrangement of flue gas recirculation lines to avoid corrosion caused by sulfur trioxide in flue gas. BHK's original technology for sulfur trioxide removal consists of a lower-temperature heat exchanger and an ESP. This arrangement reduces sulfur trioxide by cooling the flue gas just upstream of the ESP. We adopted this technology in the oxy-fuel combustion system to remove sulfur trioxide and prevent acid corrosion in the flue gas recirculation lines back to the mills.

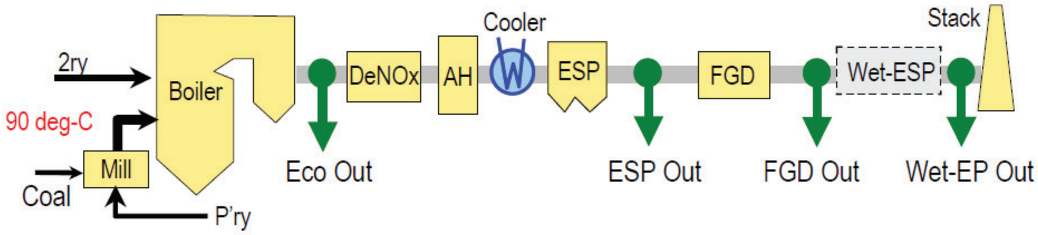
Another problem is heat loss with recirculation [7][9]. Several flue gas recirculation arrangements with heat exchangers were studied with simulation software, CHEMCAD, to estimate heat balance. (Fig.8)

Case study results show that a suitable system configuration was (a) recirculation gas extraction from ESP outlet, (b) heat exchanger outlet gas temperature of 90 deg-C and (c) oxygen mixing point upstream of AH. In this system, existing equipment such as the boiler, fans, AH, ESP and FGD are used and new equipment such as recycle gas ducts, GRF and gas coolers (heat exchanger) are installed (Fig.9).

Lastly, efficiency of retrofitted plants was estimated. The overall efficiency impact of oxy-combustion retrofit includes energy losses due to ASU, CPU and other auxiliary equipment, as well as a significant increase in power output due to the heat recovery by the new sulfur trioxide removal system.

A large increase power of LP turbine output was obtained (18MW for a 500MW class unit) because the gas cooler preheats boiler feed water and reduces steam extraction from the LP turbine.

Improvement of plant efficiency by BHK oxy-fuel combustion system is shown in Table 2. Total value is 2.0% improved of plant efficiency.



No.	Oxidant	GR point (@exit)		+Cooler
		2ry(Combustion Air)	P'ry(Mill Air)	Temp. deg-C
A-1	Air	N/A	N/A	N/A
O-1	Oxygen	ESP	ESP	N/A
O-2	↓	ESP	ESP	140
O-3	↓	ESP	FGD	↓
O-4	↓	FGD	FGD	↓
O-5	↓	Eco	FGD	↓
O-6	↓	Eco	Wet-ESP	↓
O-7	↓	ESP	ESP	90
O-8	↓	ESP	FGD	↓
O-9	↓	Eco	ESP	↓
O-10	↓	Eco	FGD	↓

Fig.8 System case studies for 500MW Class Power Plant [7]

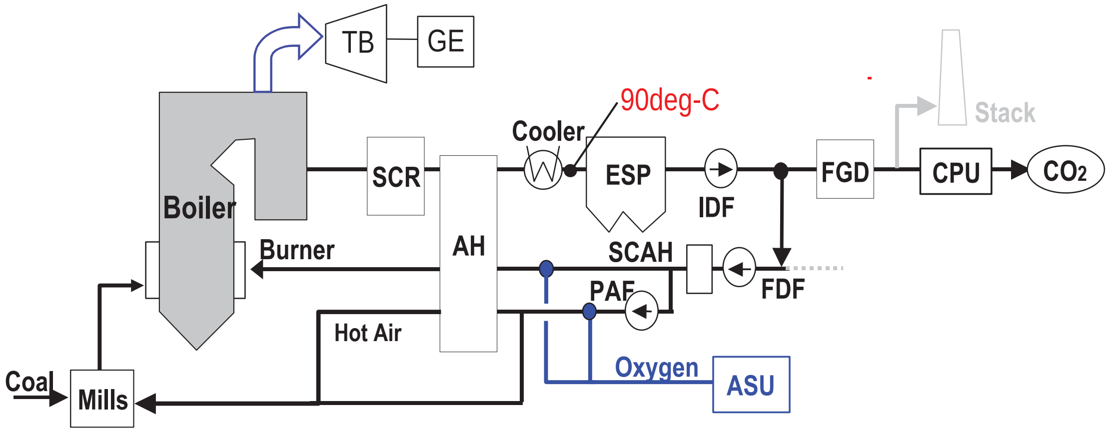


Fig.9 Oxy-combustion system studied for an existing 500MW class boiler [7][9]

Table 2. Improvement of plant efficiency by BHK oxy-combustion system [7]

Item	Improvement of plant efficiency[point]
Heat recovery of gas cooler	1.5
O_2 injection upstream of gas heater	0.5
Total	2.0

3. Development of new burners for oxy-fuel combustion

3.1. Experimental apparatus

BHK has various burner types for coal combustion systems. Our NR-3 burner was originally developed for bituminous and sub-bituminous applications [10], and NR-LE burner was originally developed for lignite coal combustion. We checked the flame stability of NR3 and NR-LE burners in oxy-fuel combustion conditions using a 4MWth test facility which is a horizontal furnace with a single burner owned by BHK [8][11].

Fig.11 shows a three-dimensional view of the 4MWth combustion test facility. The maximum combustion capacity is 500 kg/h of coal. Re-circulated flue gas was taken from the duct downstream of the spray tower using a GRF and injected at the burner and the AAP (After Air Port). Oxygen gas was supplied to both the burner and the AAP lines, and their flow rates were separately measured by flow meters.

The analysis of coal tested in this study is shown in Table 3. This is a bituminous coal produced in Australia.

Basic conditions in this test were that the total stoichiometric ratio of oxygen was 1.2 and the burner stoichiometric ratio of oxygen was 0.8.

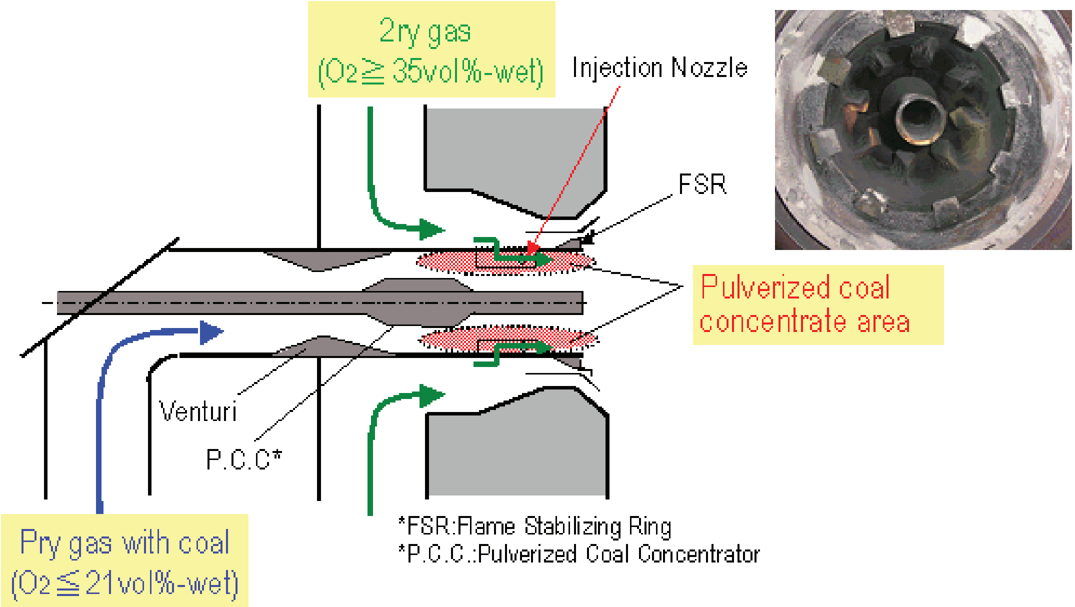


Fig.10 Configuration of NR-LE Burner [8]

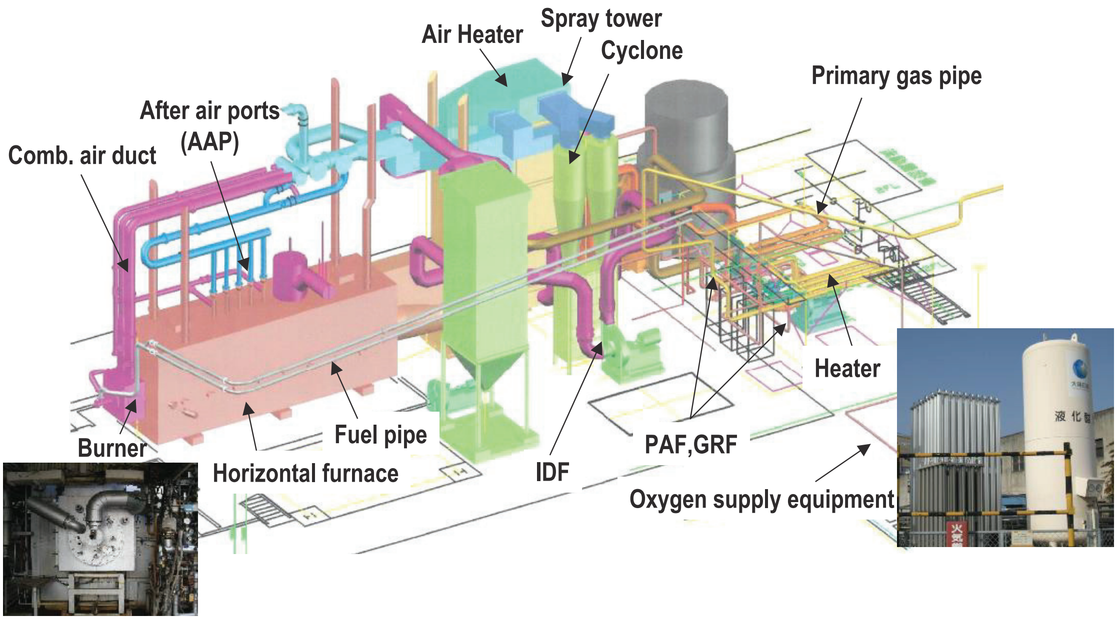


Fig.11 Three-dimensional view of 4MWth combustion test facility [8] [11]

Table 3. Analysis of the test coal

	base	unit	Coal C
HHV	air dried	kJ/kg	29,620
Proximate Analysis:			
Moisture	air dried	%	2.4
Volatile Matter	dry	%	33.3
Fixed carbon	dry	%	55.2
Ash	dry	%	11.5
Ultimate Analysis:			
C	dry ash free	%	73.2
H	dry ash free	%	4.6
O	dry ash free	%	8.4
N	dry ash free	%	1.8
S	dry ash free	%	0.5

3.2. Results and Discussions

Fig.12 shows the results of flame stability for NR-3 and NR-LE burners. For the NR-3 burner, the minimum primary O_2 limitation for flame stability is about 21%-wet. For NR-LE burner, the primary O_2 concentration can be reduced to 10%-wet without any combustion problems such as flame instability or high levels of unburned carbon.

Fig.13 shows the results of the chart at 4MWth test with an NR-LE burner. The NR-LE burner kept a stable flame during changes from air to oxy-fuel or oxy-fuel to air.

To achieve a stable combustion under oxy-fuel conditions, the NR-LE burner was designed with;

(1) O_2 concentration of primary gas maintained at 21vol%-wet or less.

(2) To enhance the ignition of pulverized coal, while secondary gas of higher O_2 concentration is supplied to the coal concentrate area of primary gas line.

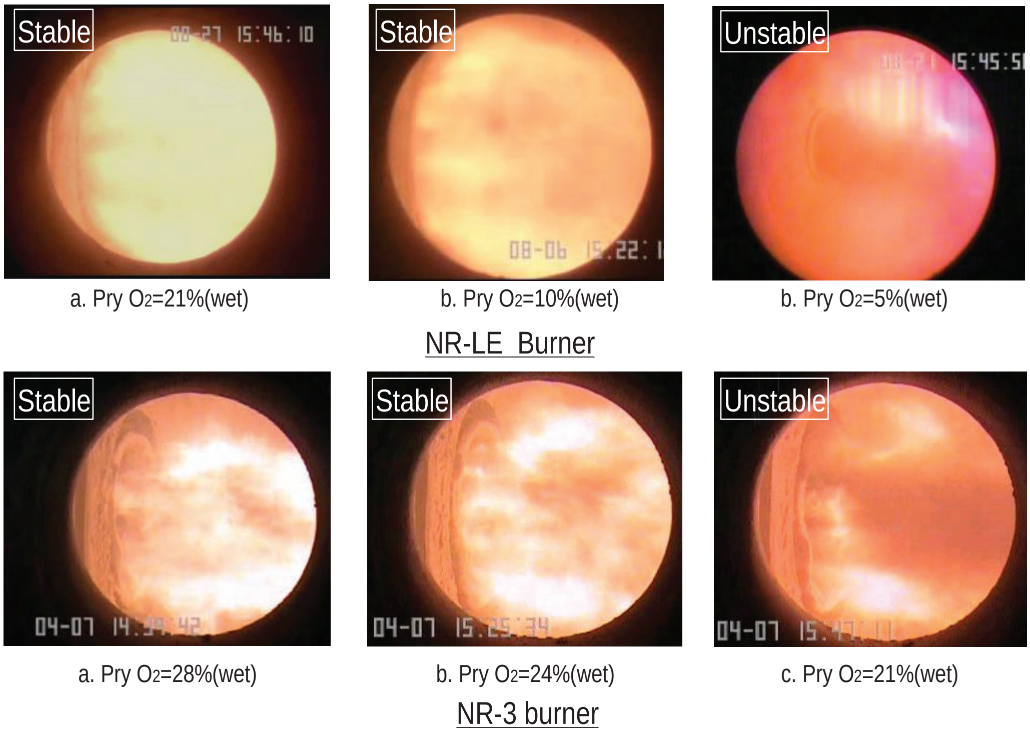


Fig.12 Flame Photographs of NR-LE and NR-3 burner (Average O_2 28%-wet) [8]

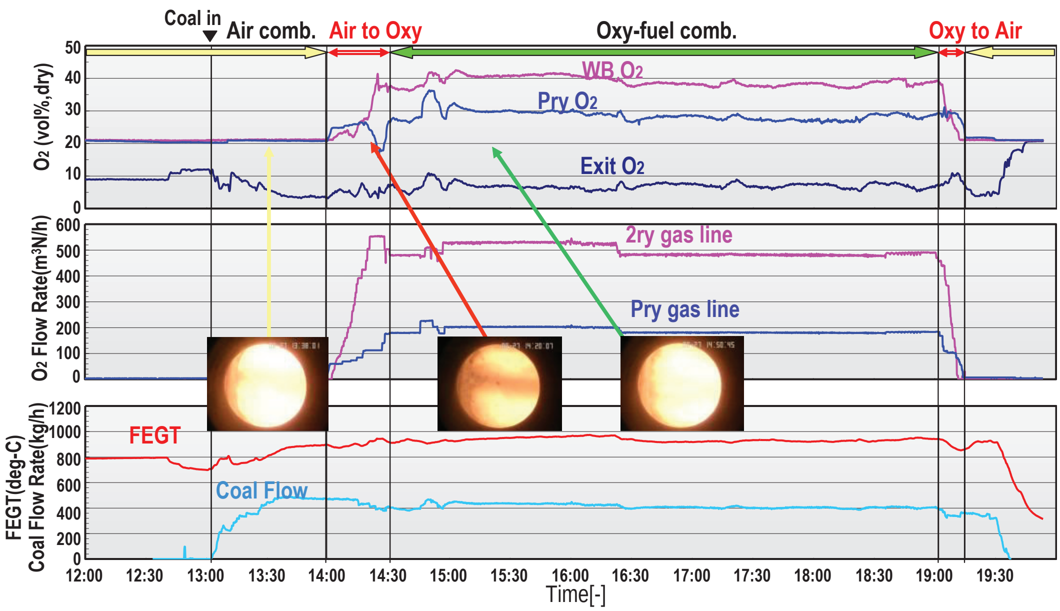


Fig.13 Time trend chart and pictures of burner flame during combustion test [8]

4. Study of boiler performance in oxy-fuel combustion conditions

4.1. Experimental apparatus

In boiler retrofits to oxy-fuel combustion, equilibrium in boiler heat adsorption air combustion is prerequisite. Effects of O_2 concentration on furnace exit gas temperatures (FEGT) and total heat absorption in the boiler were studied using numerical analysis software (CRAFT) uniquely developed by Hitachi and BHK.

4.2. Results and Discussions

Fig.14 shows furnace gas temperature distribution and FEGT calculated by CRAFT.

The results indicate that overall oxygen concentration of 27 vol% is needed to match the FEGT value of air-combustion. Therefore, it is necessary to control the oxygen concentration approximately 27 vol% for oxy-fuel combustion using an existing air combustion boiler without significant modification.

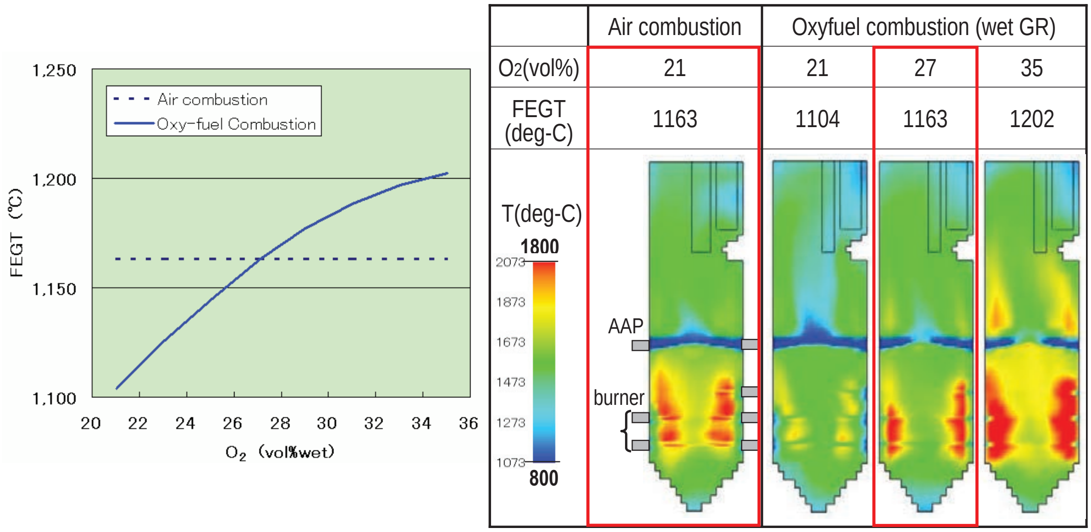


Fig.14 Simulation results for Air and Oxy-fuel combustion [9]

5. Conclusion

BHK has developed new systems for oxy-fuel combustion with high reliability and high efficiency, and we are ready for execution of actual projects. Features of the systems include:

(1) Mercury and SO_3 removal by decreasing flue gas temperatures at the ESP inlet with a cooler system.

(2) There is a large increase power of LP turbine output because the gas cooler preheats boiler feed water and reduces steam extraction from LP turbine.

(3) Stable combustion under low O_2 concentration of primary gas with NR-LE Burners is achieved.

(4) Easy and smooth changeover between air combustion and oxy-fuel combustion.

(5) Oxy-fuel combustion with O_2 concentration at 27~30 % requires the same heat absorption as Air combustion. Limited modification is enough for retrofit of existing boilers to oxy-fuel combustion under this condition.

Acknowledgements

This study was partly carried out under contract with New Energy and Industrial Technology Department Organization (NEDO) of Japan.

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